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2651 #3
a/f
3/2/02

Docket No. 33726-17
TX/PSC/D.17279/000

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of: Zhu, et al.		)	
Serial No.:	09/922,987	)	Examiner: Not Yet Assigned
Filed:	08/03/01	)	Group Art Unit: 2651

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For: METHOD AND APPARATUS FOR DYNAMICALLY MEASURING THE FULL FLYING STATE OF A SLIDER

Commissioner for Patents
Washington, D.C. 20231

CERTIFICATE OF MAILING

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on 11-12-01

Pamela K. Kerr

Signature Pamela K. Kerr

CLAIM OF PRIORITY UNDER 35 U.S.C. §119

Under the provisions of 35 U.S.C. §119, Applicant hereby claims the priority of Singapore patent application No. 200004355-4, filed August 3, 2000. A certified copy of the Priority Document is submitted herewith.

Respectfully submitted,

JENKENS & GILCHRIST,
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Dallas2 841606 v 1, 33726.00017

REGISTRY OF PATENTS
SINGAPORE

This is to certify that the annexed is a true copy of the following Singapore patent application as filed in this Registry.

Date of Filing	:	03 AUGUST 2000
Application Number	:	200004355-4
Applicant(s)	:	DATA STORAGE INSTITUTE
Title of Invention	:	A METHOD AND APPARATUS FOR DYNAMICALLY MEASURING THE FULL FLYING STATE OF A SLIDER

Tan Kar Leng (Miss)
Assistant Registrar
for REGISTRAR OF PATENTS
SINGAPORE
01 FEBRUARY 2001

PATENTS FORM 1

SECOND SCHEDULE
SINGAPORE
THE PATENTS ACT
(CHAPTER 221)
THE PATENTS RULES

Rule 19

200004355-4
-3 AUG 2000

The Registrar of Patents
Registry of Patents

REQUEST FOR THE GRANT OF A PATENT

THE GRANT OF A PATENT IS REQUESTED BY THE UNDERSIGNED ON THE BASIS OF THE PRESENT APPLICATION.

I. Title of Invention	A METHOD AND APPARATUS FOR DYNAMICALLY MEASURING THE FULL FLYING STATE OF A SLIDER			
II. Applicant(s) (See note 2)	(a) Name	DATA STORAGE INSTITUTE		
	Body Description/ Residency	A company limited by guarantee		
	Street Name & Number	DSI Building, 5 Engineering Drive 1 (off Kent Ridge Crescent, NUS)		
	City			
	State			
	Country	SINGAPORE 117608		
	(b) Name			
	Body Description/ Residency			
	Street Name & Number			
	City			
	State			
	Country			
	(c) Name			
	Body Description/ Residency			
	Street Name & Number			
	City			
	State			
	Country			
III. Declaration of priority (see note 3)	Country/Country Designated		File no.	
	Filing Date			
	Country/Country Designated		File no.	
	Filing Date			
	Country/Country Designated		File no.	
	Filing Date			

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 200004355-4

IV. Inventors (See note 4) (a) *The applicant(s) is/are the sole/joint inventor(s).*	☐ *Yes* ☒ *No*
(b) *A statement on Patents Form 8 is/~~will be~~ furnished*	☒ *Yes* ☐ *No*
V. Name of Agent (if any) (See note 5)	**ALLEN & GLEDHILL**

VI. Address for Service (See note 6)

Block/Hse No	36	*Level No*	18
Unit No/PO Box	01	*Postal Code*	068877
Street Name	ROBINSON ROAD		
Building Name	CITY HOUSE		

VII. Claiming an earlier filing date under section 20(3), 26(6) or 47(4). (See note 7)

Application No	
Filing Date	

VIII. Invention has been displayed at an International Exhibition (See note 8)	☐ *Yes* ☒ *No*
IX. Section 114 requirements (*See note 9*)	*The invention relates to and/or used a micro-organism deposited for the purposes of disclosure in accordance with section 114 with a depositary authority under the Budapest Treaty.* ☐ *Yes* ☒ *No*

X. Check List (To be filled in by applicant or agent)

A. The application contains the following number of sheet(s):-

1. Request	3	*sheets*
2. Description	13	*sheets*
3. Claim(s).	5	*sheets*
4. Drawing(s).	10	*sheets*
5. Abstract.	1	*sheet*

B. The application as filed is accompanied by:-

1. Priority document	
2. Translation of priority document	
3. Statement of Inventorship & right to grant	
4. International Exhibition Certificate	

X. Signature(s) (See note 10)

Applicant (a)	
Date	3 August 2000
Applicant (b)	
Date	
Applicant (c)	
Date	

NOTES:

1. This form when completed, should be brought or sent to the Registry of Patents together with the prescribed fee and 3 copies of the description of the invention, and of any drawings.

2. Enter the name and address of each applicant in the spaces provided at paragraph II. Names of individuals should be indicated in full and the surname or family name should be underlined. The names of all partners in a firm must be given in full. The place of residence of each individual should also be furnished in the space provided. Bodies corporate should be designated by their corporate name and country of incorporation and, where appropriate, the state of incorporation within that country should be entered where provided. Where more than three applicants are to be named, the names and address of the fourth and any further applicants should be given on a separate sheet attached to this Form together with the signature of each of these further applicants.

3. The declaration of priority at paragraph III should state the date of the previous filing, the country in which it was made, and indicate the file number, if available. Where the application relied upon in an International Application or a regional patent application e.g. European patent application, one of the countries designated in that application [being one falling under the Patents (Convention Countries) Order] should be identified and the name of that country should be entered in the space provided.

4. Where the applicant or applicants is/are the sole inventor or the joint inventors, paragraph IV should be completed by marking the 'YES' Box in the declaration (a) and the 'NO' Box in the alternative statement (b). Where this is not the case, the 'NO' Box in declaration (a) should be marked and a statement will be required to be filed on Patents Form 8.

5. If the applicant has appointed an agent to act on his behalf, the agent's name should be indicated in the spaces available at paragraph V.

6. An address for service in Singapore to which all documents may be sent must be stated at paragraph VI. It is recommended that a telephone number be provided if an agent is not appointed.

7. When an application is made by virtue of section 20(3), 26(6) or 47(4), the appropriate section should be identified at paragraph VII and the number of the earlier application or any patent granted thereon identified.

8. Where the applicant wishes an earlier disclosure of the invention by him at an International Exhibition to be disregarded in accordance with section 14(4)(c), then the 'YES' box at paragraph VIII should be marked. Otherwise the 'NO' box should be marked.

9. Where in disclosing the invention the application refers to one or more micro-organisms deposited with a depository authority under the Budapest Treaty, then the 'YES' box at paragraph IX should be marked. Otherwise the 'NO' box should be marked.

10. Attention is drawn to rules 90 and 105 of the Patent Rules. Where there are more than three applicants, see also Note 2 above.

11. Applicants resident in Singapore are reminded that if the Registry of Patents considers that an application contains information the publication of which might be prejudicial to the defence of Singapore or the safety of the public, it may prohibit or restrict its publication or communication. Any person resident in Singapore and wishing to apply for patent protection in other countries must first obtain permission from the Singapore Registry of Patents unless they have already applied for a patent for the same invention in Singapore. In the latter case, no application should be made overseas until at least two months after the application has been filed in Singapore.

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Application Filing Date: / /
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A METHOD AND APPARATUS FOR DYNAMICALLY MEASURING THE FULL FLYING STATE OF A SLIDER

Field of the invention

The invention relates to the measurement of the spatial orientation of a recording head slider with respect to an adjacent disk surface. The invention is particularly applicable to magnetic disk drives, eg for communicating the flying state of magnetic recording head sliders, or specific parameters for the slider such as minimum flying height, pitch angle or roll angle.

Background of the invention

The magnetic disk and head are key components of magnetic disk drives such as hard disk drives. When the disk drive is in operation, the magnetic disk rotates at speed, and the magnetic head slider is positioned a small distance above the magnetic disk due to the well known "air bearing" effect.

The distance between the slider and the surface of the magnetic disk ("head-disk spacing") is a critical parameter relating to the recording density and reliability of the disk drive. A reduction in the head-disk spacing can be used to achieve an increase in recording density, though at the expense of drive reliability.

In existing drives, the head-disk spacing is around 25 nm. It is expected that head-disk spacing will fall below 10 nanometer levels in due course. Accordingly, the measurement of slider position relative to the surface of a magnetic disk is becoming increasingly important for achieving design targets while ensuring product quality.

At present, optical techniques exist to test the flying height of a magnetic head slider before its installation in a magnetic drive. These techniques are generally recognised as unsatisfactory as the tolerance in measurement becomes more

critical.

Accordingly, it is an object of the invention to address these and other problems associated with existing techniques by providing an improved method for measurement of the spatial orientation of a recording head slider with respect to an adjacent disk surface.

Summary of the invention

The inventive concept resides in a recognition that the spatial orientation of a slider relative to the surface of a magnetic disk surface can be dynamically measured by simultaneously measuring a number of parameters associated with a light beam(s) reflected from a region between the slider and a magnetic disk.

Thus, the invention provides a method of dynamically determining the spatial orientation of a slider positioned above a magnetic disk, the method including:

directing one or more incident beams of light to a slider-disk region between the slider and the magnetic disk;

simultaneously measuring values derived from one or more beams of light reflected from said slider-disk region, said simultaneously measured values respectively corresponding with multiple points on the surface of the slider which are spaced apart from each other; and

calculating the spatial orientation of the slider based on said simultaneously measured values.

Preferably, the number of said multiple values is equal to or greater than the number of degrees of freedom said slider has in its movement above the magnetic disk. Preferably, said number of degrees of freedom, and said number of multiple parameters are both equal to three.

Preferably, the spatial orientation of the slider is calculated in terms of three parameters - namely a distance from the magnetic disk surface, a pitch angle and a roll angle.

Preferably, calculating the spatial orientation of the slider involves a determination of the distance between the surface of the magnetic disk, and respective spaced points on said slider, so that calculations are readily performed to determine the spatial orientation of the slider.

In one embodiment, a single beam of light having multiple discrete wavelengths is used. Preferably, in this first embodiment, a light source having two distinct frequencies is directed to the slider-disk interface. The measurement of multiple parameters preferably involves the measurement of the intensity of each of the two frequency components of the light beam after it has been reflected from different points on the surface of the slider.

Preferably, the light reflected from different points is measured using a light beam having a width sufficient to encompass those different points. Preferably, an series of mirrors having suitably located pinholes corresponding with those different points is used.

In a second embodiment, different beams are used to independently monitor different points. Preferably, the beams are incident to the region between the magnetic disk and the slider at an angle off normal.

Description of drawings

Fig. 1 is a schematic drawing in side elevation of a slider/disk interface;

Fig. 2 is a schematic drawing representing a measuring apparatus for dynamically measuring the spatial orientation, ie the full flying state, of a slider in relation to a magnetic disk, according to a first embodiment of the invention;

Fig. 3 is a schematic drawing of a detector used in the embodiment shown in Fig. 2;

Fig. 4 is a representation of a slider in plain view, with three measurement points indicated on the slider;

Fig. 5 is a schematic drawing of a recording head flying a small distance from a magnetic disk, with various parameters indicated;

Fig. 6 is a schematic drawing indicating the location of measurement points for measuring the read/write element flying height of a slider;

Fig. 7 is a schematic drawing indicating the location of measurement points for measuring the minimum flying height of a slider;

Fig. 8 is a schematic drawing representing a measuring apparatus for dynamically measuring the spatial orientation, ie the full flying state, of a slider in relation to a magnetic disk, according to a second embodiment of the invention;

Fig. 9 is a schematic drawing of one of the optical systems of the apparatus depicted in Figure 8; and

Fig. 10 is a graph representing the typical relationship between intensity of a reflected fringe pattern and flying height.

Description of embodiments

First embodiment

Fig. 1 shows a typical orientation of a slider 53 with respect to a magnetic disk 52. The disk 52 is installed on a spindle (not shown) and rotates with the spindle. The slider 53 is positioned a small distance from the disk 52 by virtue of the air

bearing effect as the disk 52 rotates. The slider 53 has an air bearing surface 63 facing the disk 52.

The spacing 60 between the air bearing surface 63 and the disk surface 62 is referred to as the slider-disk spacing, or the "flying height" of the slider 53. The slider 53 is able to move in three degrees of freedom which are most conveniently described in terms of vertical height, pitch angle and roll angle. The spatial orientation or "full flying state" of the slider 53 in relation to the disk 52 can be defined by these three parameters.

Fig. 2 shows an apparatus for dynamically measuring the spatial orientation of a slider 53. A light source 12 produces a light beam 1 consisting of multiple discrete wavelengths of light. The light source 12 can be, for example, a Xenon lamp, one or more laser diodes, or a mercury arc lamp. When it is incident on the slider 53, the light beam 1 is sufficiently wide to cover a region of air bearing surface 63 containing a number of selected measurement points, as further discussed below.

Accordingly, the reflected light beam 4 contains enough information to determine the spatial orientation of the slider 53. Information is derived in relation to the distance between the disk 52 and three discrete spaced points on the air bearing surface 63 of the slider 53, and a determination is consequently made as to the spatial orientation of the slider 53 with respect to the disk 52.

A series of three distinct stages of optical componentry is used to measure the reflected light intensities associated with three discrete spaced points on the air bearing surface 63.

In a first stage, light output as beam 1 from the light source 12 passes through collimating optics 13, after which it is incident on a beamsplitter 14. The beamsplitter 14 directs the beam 1 to a region at the interface of the slider 53 and the disk 52 via a microscope objective lens 15. Beam passes through disk 52,

which is transparent, and is reflected as beam 4 from air bearing surface 63.

Reflected light 4 from the head-disk interface enters a mirror 16 having a pinhole nears its centre. A portion of beam 4 passes as light beam 5 through the pinhole to a first detector component 17 which converts the intensity profile of the light beam 5 into corresponding electrical signals inputed to an analog-to-digital converter 43 connected to a computer 44.

In a second stage light beam 6 reflected from mirror 16 is directed to a mirror 22 having a pinhole near its centre. Light beam 7, which passes through the pinhole in the mirror 22, is directed to a second detector component 23 similar to detector component 17. The detector 23 records the intensity of light beam 7 and inputs corresponding electrical signals to A/D converter 43. Again, the recorded values are sampled and stored in the computer 44.

In a third stage, light beam 8 reflected from the the mirror 22 is directed to mirror 32 also having a pinhole near its centre. A transmitted light beam 9 is directed to a third detector component 33 similar to both the first and second detectors 17 and 23. As with the first and second stages, light intensity is recorded by the detector 33, and is ultimately read by the computer 44 as with detectors 17 and 23.

The pinholes in the first, second and third mirrors 16, 22 and 32 respectively correspond with three distinct and spaced measurement points on the air bearing surface 63 of the slider 53. The cascaded series of mirrors is used to progressively isolate (using the respective pinholes) light reflected from each of the three spaced points on the air bearing surface 63. The detectors 17, 23, 33 are used to measure light reflected from these three respective points.

Light beam 10 reflected from mirror 32 is passed to a CCD camera 34 which is connected to a video display 42. This provides a visual indication of the slider

which can be viewed by an operator.

Fig. 3 shows an example of the components of the first detector 17. The detector is structured to allow a determination of the intensities of two wavelengths included in the light beam 5 passed to the detector 17. The second and third detectors 23 and 33 have the same configuration and function in the same manner as the first detector 17.

A beamsplitter 171 reflects light beam 172 of one wavelength, which is preferably 436 nm, towards a 436 nm interference filter 173 and then to photodetector 174. The beamsplitter 171 preferably has an anti-reflection coating for 85% to 95% reflectance at 436 nm and 85% to 95% transmittance at 580 nm. A 580 nm light beam 175 passing through the beamsplitter 171 traverses a 580 nm interference filter 176 and enters photodetector 177. A separate signal is generated for each wavelength, and each signal generated by the photodetectors 174 and 177 is connected to the analog-to-digital converter 43. Accordingly, a digital measurement of the light intensities of the two wavelengths is made for use by the computer 44 as later described.

Wavelengths 436 nm and 580 nm are conveniently used as they are two of the peaks lines of emission of the mercury arc lamp. Alternatively, other wavelengths can equally well be used, such as 404 nm and 546 nm which are other peak lines of the mercury arc lamp.

Once the two light intensities are measured, the flying height can be measured, as now explained. According to the optical thin film theory, the intensity I of the reflected fringe pattern is

$$I = \frac{r_1^2 + r_2^2 + 2r_1r_2\cos\delta}{1 + r_1^2r_2^2 + 2r_1r_2\cos\delta}$$

where, r_1 is the reflectance of the disk surface 62 of the disk 52;

r_2 is the reflectance of the air-bearing surface 63 of the slider 53;

δ is the phase difference corresponding to the light path difference between successive transmitted light waves.

The phase difference δ is:

$$\delta = \frac{4\pi n h \cos\theta_1'}{\lambda} - \phi$$

where, λ is the wavelength of the light;

n is the refractive index of the medium between the disk surface 62 and air-bearing surface 63, nominally the medium is air; and

θ_1' is the angle of incidence of the light wave onto the air-bearing surface 63;

ϕ is phase shift on reflection from surface 63, which is dependent on the refractive index of air-bearing surface 63.

Fig. 10 shows the typical relationship between the intensity of the resultant fringe pattern as the flying height is varied between zero and 500 nm. The parameters are as follows: λ is 436 and 580 nm respectively; the refractive index of the disk surface 62, air and air-bearing surface 63 are 1.52, 1.0, and 2.15 + j* 0.5, respectively; θ_1' is zero degree. The light intensity is normalized by the $(I-I_{min})/(I_{max}-I_{min})$, where I_{max} is a maximum of the light intensity, I_{min} is a minimum of the light intensity.

According to the above expression, the intensity of reflected light is dependent on the following parameters; wavelength λ of the incident light; the incident angle;

the refraction coefficients of the disk 52, the air medium and the air-bearing surface 63; and slider-disk spacing. All parameters are known except the slider-disk spacing. Thus, if the measured light intensities are determined, the slider-disk spacing can accordingly be calculated.

With reference to Fig. 10, if the measured light intensity is around I_1 for 436 nm wavelength, the slider-disk spacing will be near s_1 or s_2 or s_3. However, of the intensity of light with 580 nm wavelength is I_2, the possible slider-disk spacings are s_1 or s_4 or s_5. Accordingly it is deduced that the correct slider-disk spacing is s_1.

Fig. 4 shows the slider 53, and various points on the surface of the slider 53. As an example, the distance from the surface of the disk 52 to points A (x_a, x_b), B (y_a, y_b) and C (z_c, z_c) can be directly measured using the apparatus described above, and these three measurements used to dynamically calculate the spatial orientation of the slider 53.

Direct measurement of the pole tip G (x_g, y_g) of the slider 53 is difficult, due to the variation in material and optical constants in this region of the slider 53, compared with the body of the slider 53. Also, the flying height of the corner points M1, M2, M3, M4 cannot be measured directly. The method of calculating the flying height of these points, and the pitch angle and roll angle of the slider 53 is described as follows.

Instead, points A, B and C are suitably chosen as reference points. Once the relative intensities of the discrete wavelengths of the reflected beam is measured, the flying height of each of these points can be determined. This is achieved using the same technique as described above.

Fig. 5 shows a profile of the slider 53. The flying heights of reference points A, B and C above the surface of the magnetic disk 52 are denoted H_a, H_b and H_c

respectively. Also, points A, B and C are attributed planar co-ordinates (A (x_a, y_a), B (x_b, y_b) and C (x_c, y_c)) in a plane parallel with the surface of the magnetic disk 52.

With this reference, the position of points A, B and C are for convenience chosen so that:

$$x_a = x_b$$

$$y_c = \frac{y_a + y_b}{2}$$

Since pitch angle (designated α) and roll angle (designated β) are both less than 0.001, $\cos(\alpha)$ very closely approximates to 1. This approximation simplifies the calculation of the pitch angle α and roll angle β using the equations directly below.

$$\alpha = \tan^{-1}\left(\frac{H_a + H_b + P_a + P_b - 2H_c - 2P_c}{2 \cdot (x_c - x_a)}\right)$$

$$\beta = \tan^{-1}\left(\frac{H_b + P_b - H_a - P_a}{y_b - y_a}\right)$$

The minimum flying height of the slider (H_{min}) can be determined using any appropriate algorithmic technique once the values of each of the respective heights are determined.

$$H_{min} = \min(H_{m1}, H_{m2}, H_{m3}, H_{m4})$$

$$H_{m1} = H_c - \alpha \cdot (x_{m1} - x_c) - \beta \cdot (y_{m1} - y_c) + P_c - P_{m1}$$

$$H_{m2} = H_c - \alpha \cdot (x_{m2} - x_c) - \beta \cdot (y_{m2} - y_c) + P_c - P_{m2}$$

$$H_{m3} = H_c - \alpha \cdot (x_{m3} - x_c) - \beta \cdot (y_{m3} - y_c) + P_c - P_{m3}$$

$$H_{m4} = H_c - \alpha \cdot (x_{m4} - x_c) - \beta \cdot (y_{m4} - y_c) + P_c - P_{m4}$$

Further, the flying height (H_g) of the read/write element can be expressed as follows:

$$H_g = H_c - \alpha \cdot (x_g - x_c) - \beta \cdot (y_g - y_c) + P_c - P_g$$

Of course, different measurement points can be used, and different calculation steps performed.

Fig. 6 shows three points A, B and C arranged around the point G. The flying height of the read/write element G can be calculated from the flying heights as A, B and C by curve fitting methods.

Fig. 7 shows three points A, B and C arranged near a corner point M. The flying height of the point M can be calculated using two-dimensional curve fitting methods.

Fig. 8 shows a second embodiment of a system for dynamically measuring the spatial orientation of a slider. Instead of using a series of pinholed mirrors to isolate the light reflected from different points on the air bearing surface 63, three different beams and respective detectors are used to independently calculate the distance from the magnetic disk 52 to three respective spaced points.

Three optical assemblies 100′, 200′ and 300′ are substantially identical in structure and configuration. Each of the assemblies 100′, 200′ and 300′ can use the same wavelengths and incident angles or different wavelengths and/or incident angles. The different wavelengths and incident angles can be independently chosen.

Position adjustment assemblies 101′, 201′ and 301′ are used to position their respective optical assemblies 100′, 200′ and 300′ so that those optical

assemblies are located to measure the height of three suitable respective points A, B and C.

In this way, the spatial orientation of the slider 53 can be measured by the following steps:

(a) selecting the position of points A, B and C on the air bearing surface 63 of the slider 53;

(b) adjusting the assemblies 101′, 201′ and 301′ to position the optical assemblies 100′, 200′ and 300′ so that the flying heights of points A, B and C are measured;

(c) measuring the distance between the disk 52 and the points A, B and C on the air bearing surface 63; and

(d) calculating the spatial orientation of the slider 53 based on the measured distances.

The lamp source and detector can be the same as the first embodiment (that is, as illustrated in Fig. 2), though this need not be the case.

Fig. 9 shows an example of the optical assembly 100′ indicated in Fig. 8. Optical system 100′ includes a light source 11′ which provides a light beam 1′ having respective non-zero orthogonal polarisation vectors *s* and *p*. A focussing lens 12′ directs light 1′ to a polarising element 13′ which modifies the polarisation of the light 1′. The polarisation of the light 1’ is adjusted to provide a better signal-to-noise ratio in measured values.

The resulting light 2′ is directed to a region between the slider 53 and the disk 52 at an incident angle typically between zero and 80°.

The reflected light 3′ from the head-disk interface passes through a lens 14′ and is then directed to phase shift component 15′ which adjusts the phase difference of the *s*- and *p*-type polarisations in the light 3′.

The light 3′ then passes through a filter 16′ and enters a detector 17′ similar to the detector 17 used in the first described embodiment. The detector 17′ measures the intensity of light in each polarisation direction, and well as the combined intensity. This information is recorded in the computer 44 via the analog-to-digital card 43.

Accordingly, instead of measuring the intensities of two different wavelengths of light in one beam, the relative intensities of each orthogonal polarisation can be measured as an alternative method of determining the distance from the magnetic disk 52 to three spaced points A, B and C on the slider 53.

Once the flying height calculations are performed, the spatial orientation or full flying state of the slider 53 can be calculated in a similar manner to that described in relation to the first embodiment.

CLAIMS

1. A method of dynamically determining the spatial orientation of a slider positioned above a magnetic disk, the method including:

   directing one or more incident beams of light to a slider-disk region between the slider and the magnetic disk;

   simultaneously measuring values derived from one or more beams of light reflected from said slider-disk region, said simultaneously measured values respectively corresponding with multiple points on the surface of the slider which are spaced apart from each other; and

   calculating the spatial orientation of the slider based on said simultaneously measured values.

2. A method as claimed in claim 1, further characterised in that said values are used to derive an indication of the respective distances between the surface of the magnetic disk and each of said multiple points.

3. A method as claimed in claim 1 or 2, further characterised in that the number of said multiple spaced points is equal to or greater than the number of degrees of freedom said slider has in its movement above the magnetic disk, so that the spatial orientation of the slider can be fully determined.

4. A method as claimed in claim 3, further characterised in that said number of degrees of freedom, and the number of said multiple values are both equal to three.

5. A method as claimed in any one of claims 1 to 4, further characterised in

that the spatial orientation of the slider is calculated in terms of (i) a distance from the magnetic disk surface, (ii) a pitch angle and (iii) a roll angle.

6. A method as claimed in any one of claims 1 to 5, further characterised in that said one or more beams of light each have two or more discrete wavelengths, and said values include the relative intensities of two of said two or more discrete wavelengths after reflection from the slider-disk region.

7. A method as claimed in any one of claims 1 to 5, further characterised in that said one or more beams of light have two orthogonal vectors of polarisation, and said values include the relative intensities of the two vectors of polarisation after reflection from the slider-disk region.

8. A method as claimed in claim 7, further characterised in that said one or more beams of light are incident on said slider-disk interface at an angle between 0° and 80°.

9. A method as claimed in claim 6, further characterised in that said multiple values are simultaneously measured by using a series of cascaded mirrors having pinholes to isolate reflected light respectively corresponding with each of said multiple spaced points from one beam of light reflected from the slider-disk region.

10. A method as claimed in any one of claims 1 to 8, further characterised in that said multiple values are simultaneously measured by independently using more than one of said one or more beams of light reflected from said slider-disk region.

11. A method as claimed in any one of claims 1 to 10, further characterised in

that the minimum flying height of the slider is determined once the spatial orientation of the slider is determined, and the surface geometry of the slider is known.

12. An apparatus for dynamically determining the spatial orientation of a slider positioned above a magnetic disk, the apparatus including:

optical means for directing one or more incident beams of light to a slider-disk region between the slider and the magnetic disk;

measuring means for simultaneously measuring values derived from one or more beams of light reflected from said slider-disk region, simultaneously measured values measured by said measuring means respectively corresponding with multiple points on the surface of the slider which are spaced apart from each other; and

calculating means for calculating the spatial orientation of the slider based on said simultaneously measured values.

13. An apparatus as claimed in claim 12, further characterised in that said calculating means can use said values measured by said measuring means to derive an indication of the respective distances between the surface of the magnetic disk and each of said multiple points.

14. An apparatus as claimed in claim 12 or 13, further characterised in that the number of said multiple points is equal to or greater than the number of degrees of freedom said slider has in its movement above the magnetic disk, so that the spatial orientation of the slider can be fully determined.

15. An apparatus as claimed in claim 14, further characterised in that said number of degrees of freedom, and the number of said multiple values are both equal to three.

16. An apparatus as claimed in any one of claims 12 to 15, further characterised in that the calculation means is able to calculate the spatial orientation of the slider in terms of (i) a distance from the magnetic disk surface, (ii) a pitch angle and (iii) a roll angle.

17. An apparatus as claimed in any one of claims 12 to 16, further characterised in that said optical means is able to provide one or more beams of light each have two or more discrete wavelengths, and said measuring means is able to measure values which include the relative intensities of two of said two or more discrete wavelengths after reflection from the slider-disk region.

18. An apparatus as claimed in any one of claims 12 to 16, further characterised in that said optical means is able to provide one or more beams of light have two orthogonal vectors of polarisation, and said measuring means is able to measure values which include the relative intensities of the two vectors of polarisation after reflection from the slider-disk region.

19. An apparatus as claimed in claim 18, further characterised in that said optical means is able to direct one or more beams of light to be incident on said slider-disk interface at an angle between zero and 80°..

20. An apparatus as claimed in claim 17, further characterised in that said measurement means is able to simultaneously measure said multiple values by using a series of cascaded mirrors having pinholes to isolate reflected light respectively corresponding with each of said multiple spaced points from one beam of light reflected from the slider-disk region.

21. An apparatus as claimed in any one of claims 12 to 19, further characterised in that said measurement means is able to simultaneously

measured said multiple values by independently using more than one of said one or more beams of light reflected from said slider-disk region.

22. A method as claimed in any one of claims 12 to 21, further characterised in that the calculation means is able to determine the minimum flying height of the slider once the spatial orientation of the slider is determined, and the surface geometry of the slider is known.

ABSTRACT

A METHOD AND APPARATUS FOR DYNAMICALLY MEASURING THE FULL FLYING STATE OF A SLIDER

A method for dynamically measuring the spatial orientation of a slider use in a magnetic disk drive operates by directing a light beam through a microscope to a slider-disk region between the slider and the magnetic disk. A light beam reflected from the slider-disk region is used to derive information concerning the distances between the surface of the magnetic disk drive and multiple spaced points on the slider so that a determination of the spatial position of the slider can be determined. This can be done by determining the ratio of the relative intensities of different wavelengths or vectors of polarisation in the incident light beam. The number of measured points on the slider is at least equal to the number of degrees of freedom of the slider so that the spatial position of the slider can be fully determined.

(Figure 2)

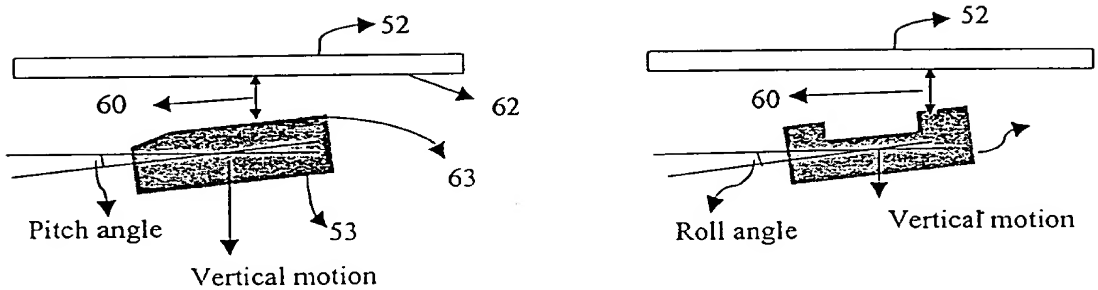
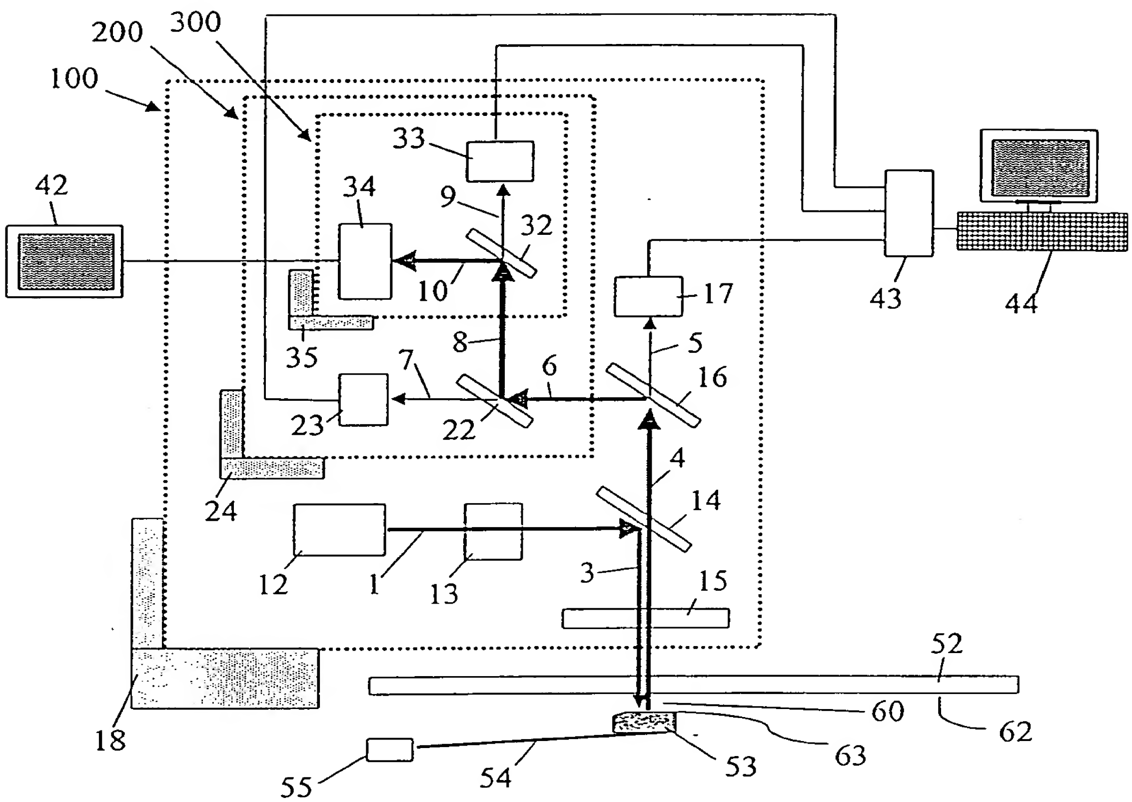

52
60
62
63
Pitch angle
53
Vertical motion
52
60
Roll angle
Vertical motion

Figure 1



200
300
100
33
42
34
9
32
10
17
43
44
35
8
5
7
6
16
23
22
24
4
14
12
1
13
3
15
52
18
60
62
63
53
55
54

Figure 2

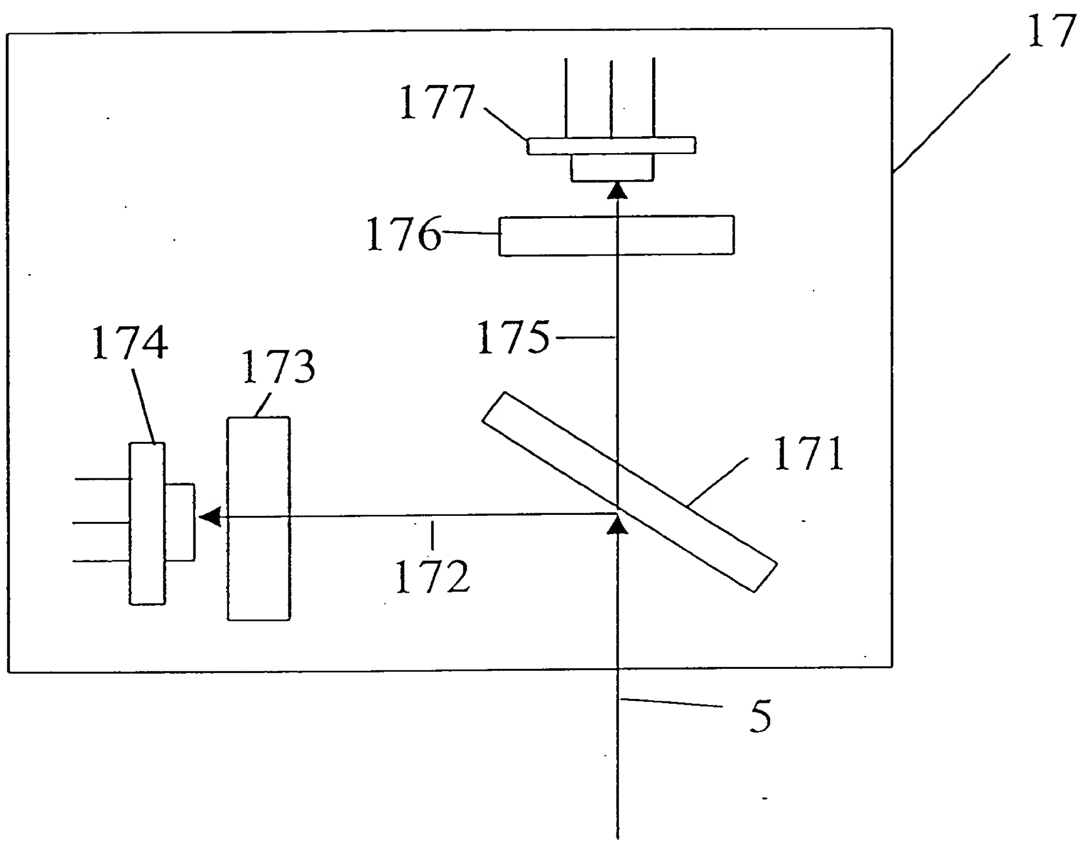


Figure 3

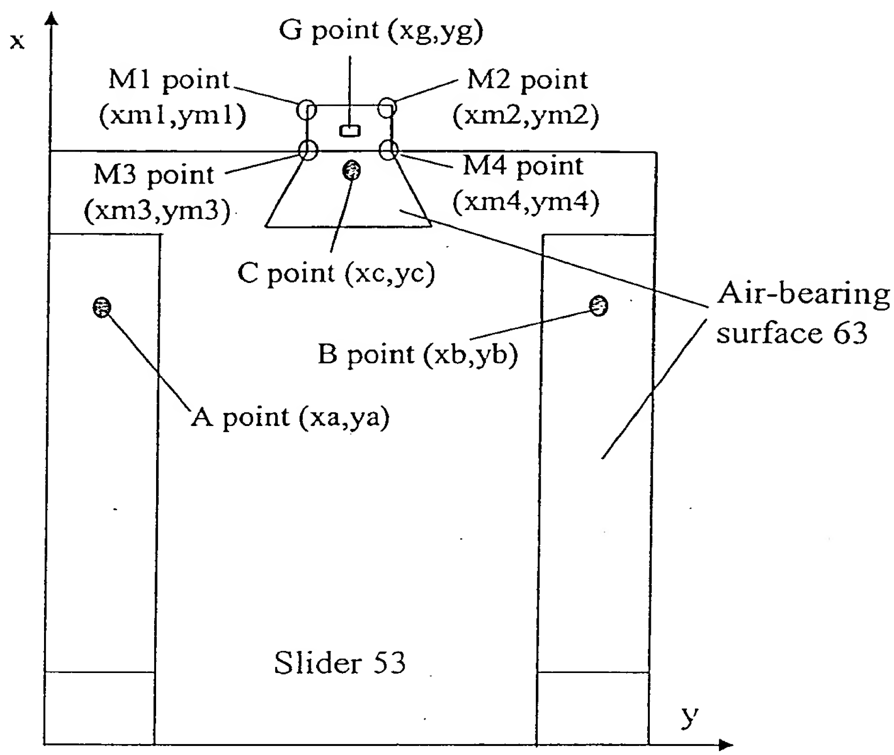

x
G point (xg,yg)
M1 point
(xm1,ym1)
M2 point
(xm2,ym2)
M3 point
(xm3,ym3)
M4 point
(xm4,ym4)
C point (xc,yc)
Air-bearing
surface 63
B point (xb,yb)
A point (xa,ya)
Slider 53
y

Figure 4

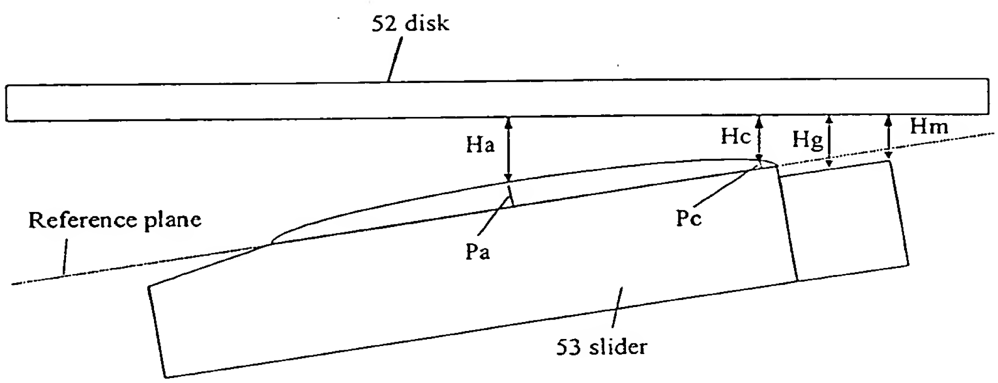


Figure 5

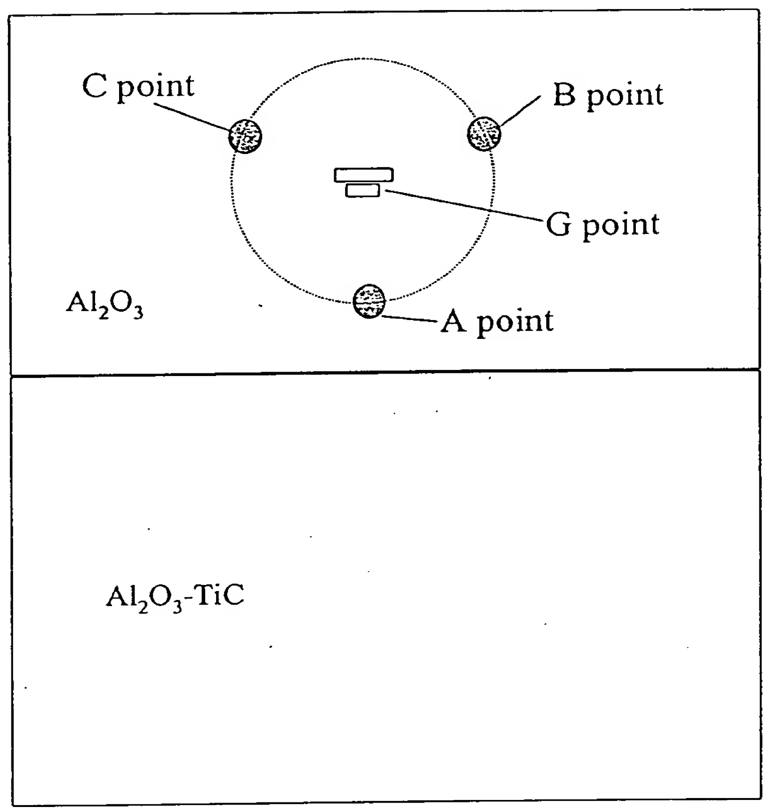


Figure 6

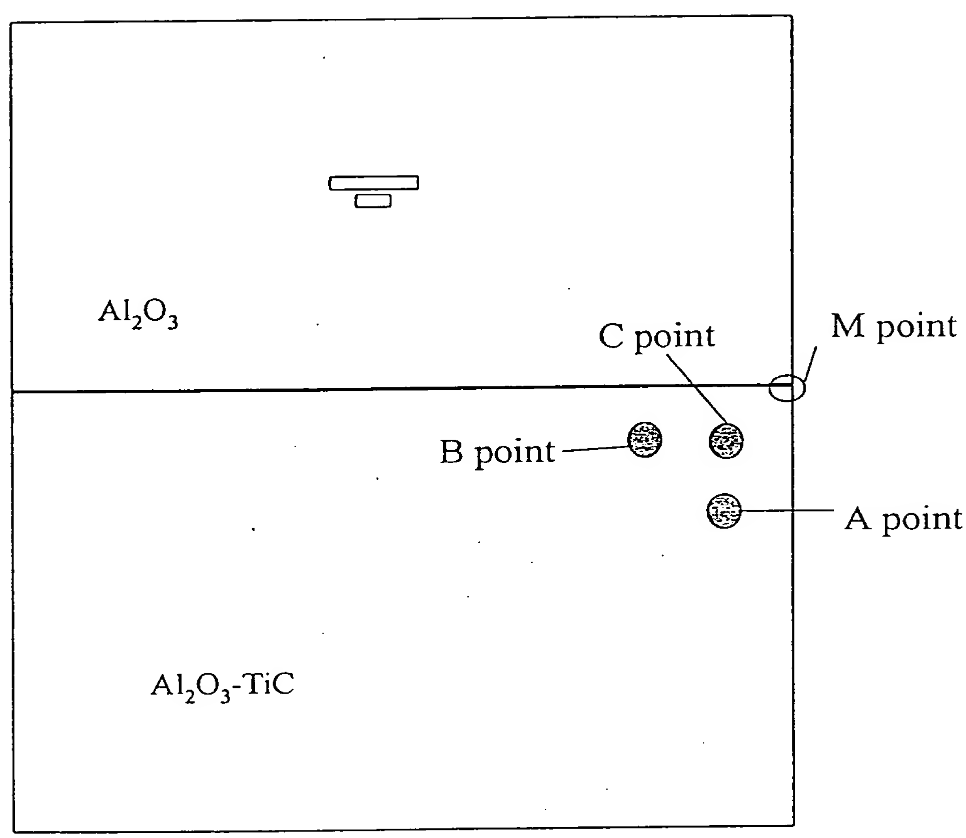


Figure 7

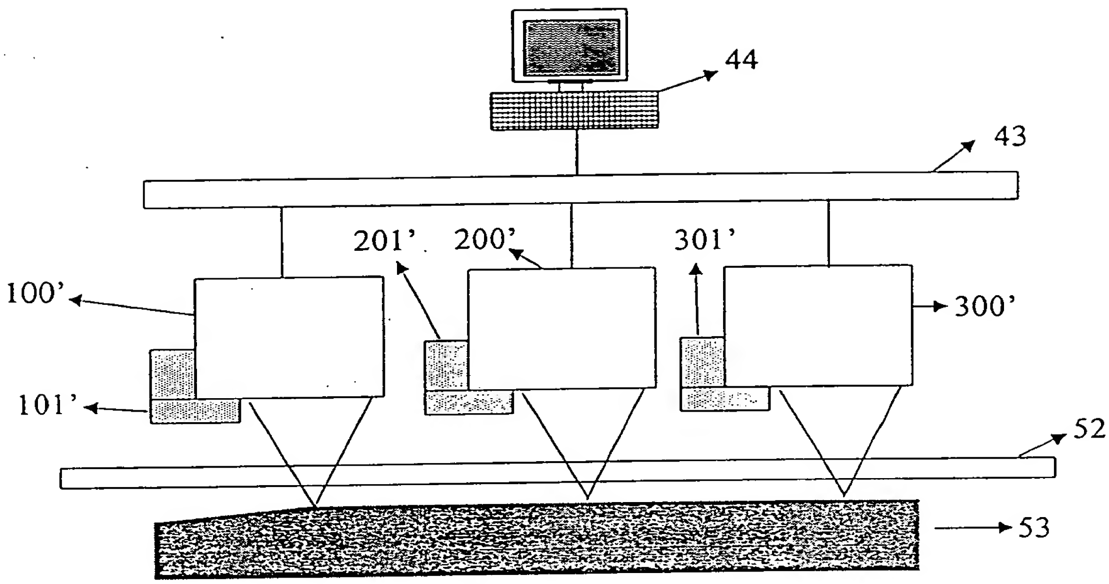


Figure 8

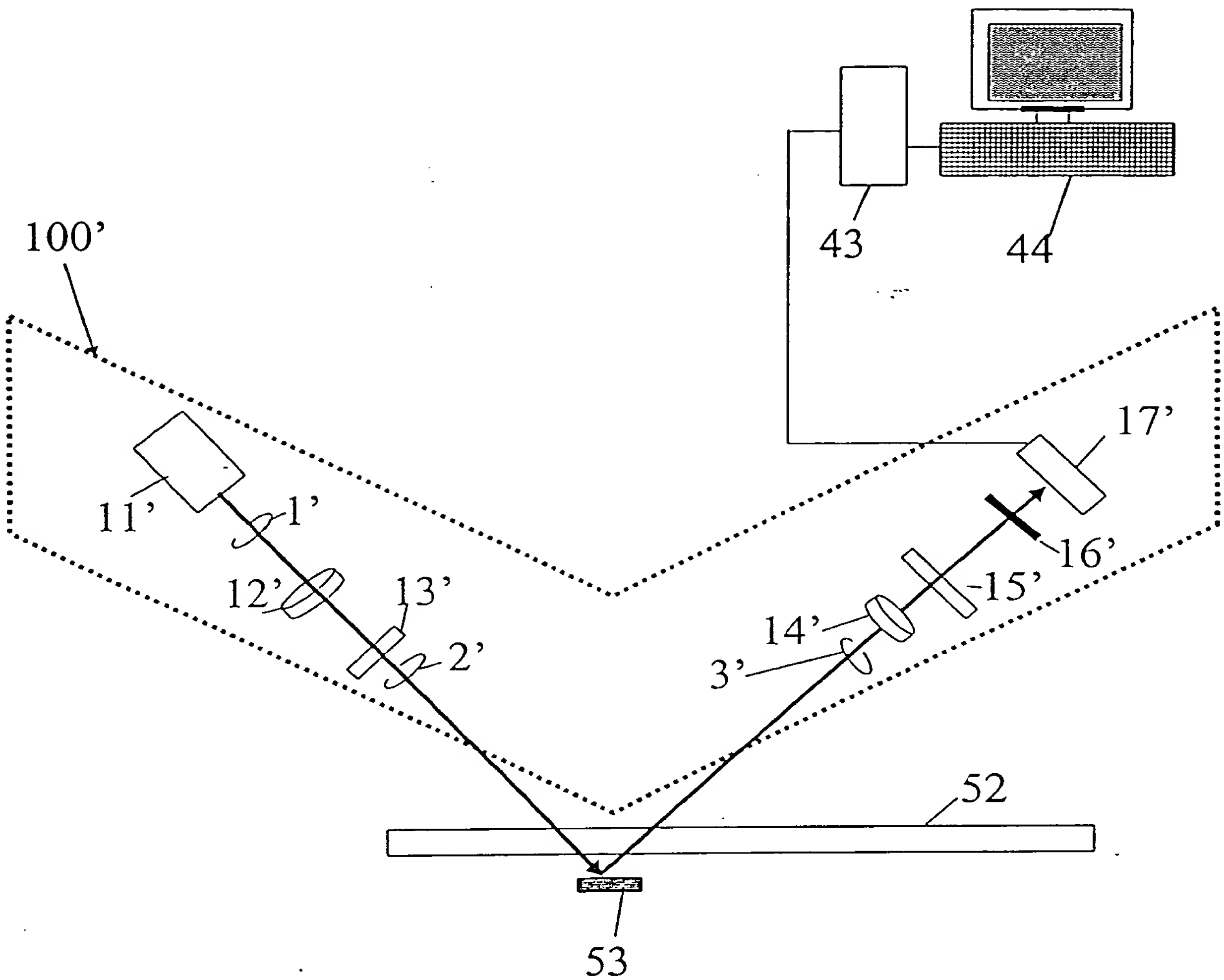


Figure 9

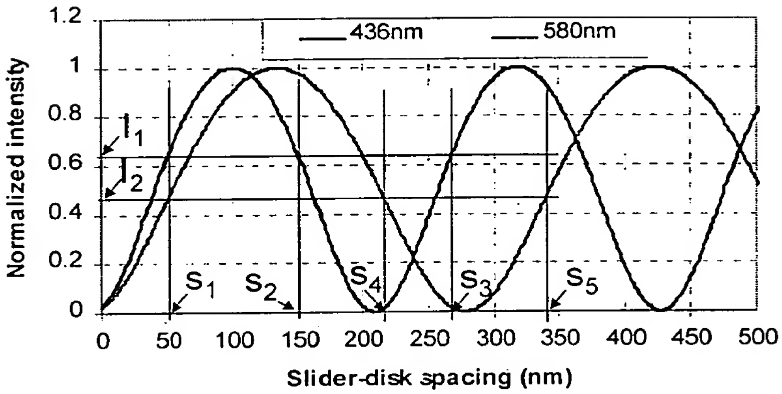

436nm
580nm
Normalized intensity
Slider-disk spacing (nm)
1.2
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
350
400
450
500
I_1
I_2
S_1
S_2
S_4
S_3
S_5

Figure 10